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August 27, 2008

Journal of Physics

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Survey of the K-shell emission from heliumlike ions with an X-ray microcalorimeter

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Abstract.

The Electron Beam Ion Trap Microcalorimeter Spectrometer (ECS) routinely surveys the K-shell x-ray spectra that fall into the energy range between 200 eV and 14,000 eV. The spectra serve as *in situ* energy references and include the K-shell emission from ions between boron at the low-energy end and krypton at the high end. Example spectra are presented of the $n = 2 \rightarrow n = 1$ emission from heliumlike noble gas ions neon, argon, and krypton, from the heliumlike transition metals iron and nickel, as well as the heliumlike ions of boron, silicon, sulfur, and germanium.

1. Introduction

The K-shell emission from highly charged heliumlike ions has played an important role in the spectroscopy of high-temperature plasmas. In magnetic fusion plasmas, for example, the emission from heliumlike argon, titanium, iron, and nickel is routinely observed to determine the central ion temperature [1-3], while the K-shell emission from boron, carbon, nitrogen, and oxygen is measured to study the concentration of indigenous impurities [4-6]. The emission from heliumlike ions of carbon, oxygen, neon, silicon, sulfur, argon, calcium, iron, and nickel is very prominent in the solar corona [7-10] and astrophysical plasmas [12, 13]. The K-shell emission of highly charged ions also dominates the x-ray spectra from comets [14].

The K-shell emission of hydrogenlike and heliumlike ions from an electron beam ion trap (EBIT) has been studied soon after the first such machine, EBIT-I, was put into operation [15]. Early on, the spectra have been studied with solid-state detectors or high-resolution crystal spectrometers, and many of their properties have been determined during these measurements [16-21].

Because the $n = 2 \rightarrow n = 1$ K-shell emission energies are rather well known both theoretically and experimentally, the lines have been used as wavelength references to measure the transition energies of lines from more complex systems. The K-shell emission lines of hydrogenlike and heliumlike ions were first used on tokamaks to measure the wavelengths of L-shell transitions of high-Z ions [22, 23]. The same technique was then applied to measuring the transition energies of neonlike and nickellike ions on the EBIT-I, EBIT-II, and SuperEBIT devices at Livermore [24-28]. Continuing this tradition, we now use the K-shell emission of highly charged ions as

calibration references to determine the energy scale of the microcalorimeter spectrometer used on SuperEBIT.

In the following we present typical measurements of the K-shell emission of heliumlike ions measured on SuperEBIT with the EBIT calorimeter spectrometer (ECS).

2. Experiment and sample spectra

The ECS instrument [29] was implemented on SuperEBIT in 2007. It represents a major upgrade of the earlier x-ray microcalorimeter [30], which was in use up to that time. The ECS consists of a 6×6 array of x-ray detector elements (pixels), where each detector functions independently. Half of the array utilizes HgTe absorbers that are $8 \mu\text{m}$ thick. These pixels are used for analyzing the x-ray emission up to roughly 15 keV. The other half utilizes HgTe absorbers that are $100 \mu\text{m}$ thick. These are used to detect x rays with energies up to roughly 60 keV. Here we only present results obtained with the low-energy pixels.

Spectra of the emission from heliumlike germanium (injected by laser blow-off) and krypton (injected as a gas) are shown in Fig. 1. The energies of the lines from these ions provide calibration at the high-end of the low-energy pixels of the ECS. Spectra of the emission from heliumlike iron and nickel are shown in Fig. 2. The resolution of the ECS is about 4.5 eV at the energy of these lines, which is over twice the resolution achieved in 2000 [31].

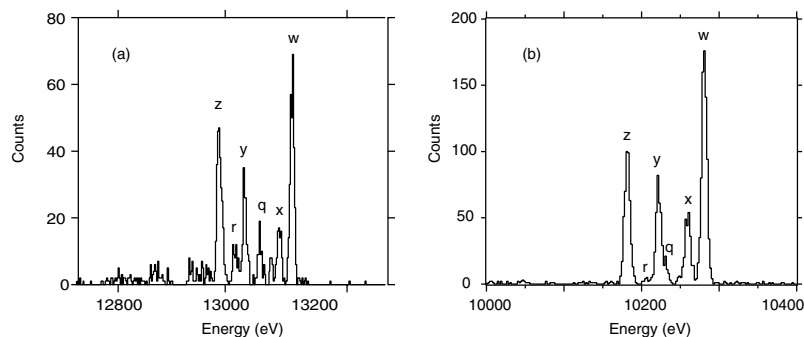


Figure 1. X-ray emission of heliumlike (a) krypton and (b) germanium measured with the ECS instrument on SuperEBIT.

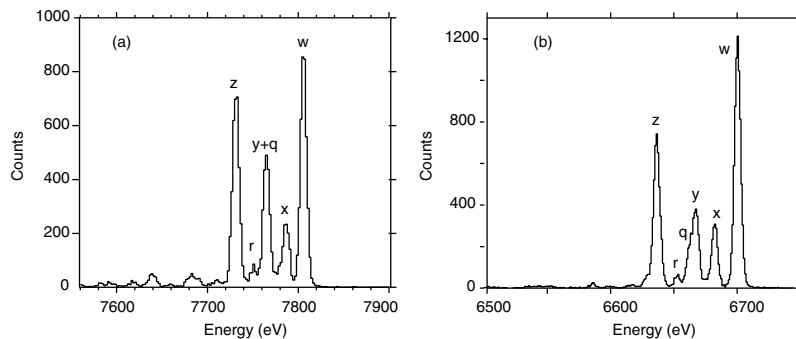


Figure 2. X-ray emission of heliumlike (a) nickel and (b) iron measured with the ECS instrument on SuperEBIT.

The spectra show the four heliumlike lines commonly labeled w , x , y , and z . These correspond to the transitions $1s2p \ ^1P_1 \rightarrow 1s^2 \ ^1S_0$, $1s2p \ ^3P_2 \rightarrow 1s^2 \ ^1S_0$, $1s2p \ ^3P_1 \rightarrow 1s^2 \ ^1S_0$, and $1s2p \ ^3S_1 \rightarrow 1s^2 \ ^1S_0$, respectively. We have also labeled two of the prominent lithiumlike

innershell satellites q and r , which correspond to the transitions $1s2s2p\ ^2P_{3/2} \rightarrow 1s^22s\ ^2S_{1/2}$ and $1s2s2p\ ^2P_{1/2} \rightarrow 1s^22s\ ^2S_{1/2}$, respectively.

In Fig. 3 we present sample spectra of the emission from heliumlike oxygen, fluorine, neon, silicon, sulfur, and argon. Oxygen, silicon, and argon are routinely found in SuperEBIT, although their sources are not yet clear - this is especially true for silicon.

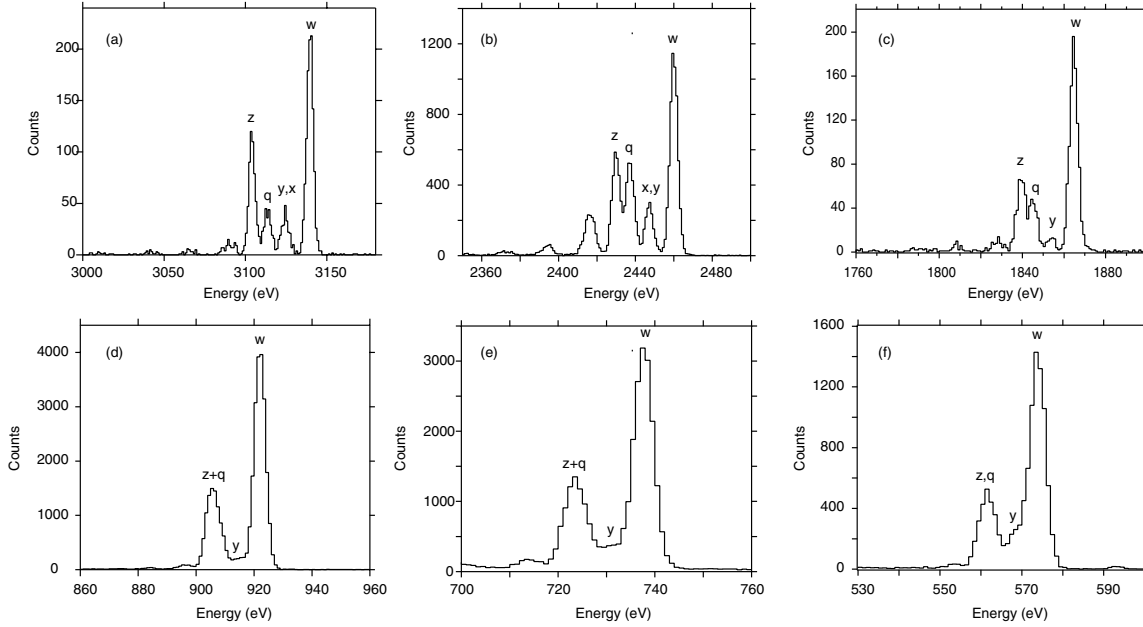


Figure 3. X-ray emission of heliumlike (a) argon, (b) sulfur, (c) silicon, (d) neon, (e) fluorine, and (f) oxygen measured with the ECS instrument on SuperEBIT.

The ECS employs ultrathin foils as thermal shields. The combined thickness of these foils is about 2182 Å of polyimide and 1434 Å of aluminum. This means that the ECS is sensitive to photons below the carbon edge. A sample spectrum of the K-shell emission of boron is shown in Fig. 4. The energy of the $1s2p\ ^1P_1 \rightarrow 1s^2\ ^1S_0$ emission of heliumlike boron, i.e. B^{3+} , is at 200 eV. The spectrum was obtained by injecting trimethyl borate into SuperEBIT via its gas injection system.

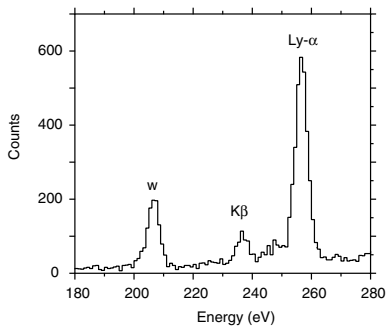


Figure 4. X-ray emission of heliumlike boron (line w and its $n=3 \rightarrow n=1$ counterpart labeled $K\beta$) and hydrogenlike boron (labeled $Ly\alpha$) measured with the ECS instrument on SuperEBIT.

3. Discussion

All spectra were formed by direct electron-impact excitation. The ionization balance varies somewhat from spectrum to spectrum, as seen in the relative amplitudes of lines q and w . It is

interesting to see that the position of q moves closer to w for ions with higher atomic number Z . Also the intercombination lines get stronger as Z increases. Line x is basically absent for ions as low as neon, but it becomes very prominent in argon and above. Line z is strong, even in low- Z spectra. This is in part because it is excited by innershell ionization, i.e., by the process $1s^2 2s + e \rightarrow 1s 2s + 2e$.

Although krypton is the element with the highest Z considered here, we point out that the emission from heliumlike ions as high as praseodymium has now been measured with a microcalorimeter on SuperEBIT [32].

Acknowledgments

This work was performed under the auspices of the U S Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and was supported in part by NASA's Astronomy and Physics Research and Analysis Program via grants to LLNL, Stanford, and GSFC.

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